

RESULTS OF THE SPATIAL RESOLUTION
SIMULATION FOR MULTISPECTRAL DATA
(RESOLUTION BROCHURES)

FINAL REPORT



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Prepared by
OAO Corporation
7500 Greenway Center
Greenbelt, Maryland 20770

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1.0 PREFACE

In promoting future Earth Resource satellite systems NASA/NOAA jointly are faced with a variety of problems in dealing with the user community's information needs in various disciplines. One of the necessary tasks is to help the user community have a uniform understanding of the variable information content of products at different levels of spatial resolution and in different spectral bands.

To address this immediate need, this task was intended to produce a relatively low-cost brochure (visual aid) that scientists and laymen could use to visualize the effects of increasing the spatial resolution of multispectral scanner images. The feedback from the user community in response to the proposed brochure would be of significant value to NASA/NOAA in planning future satellite imaging systems that would best meet the user community's requirements.

This report presents a summation of all the participants in this task, the results of their various endeavors, conclusions drawn from these results, and recommendations on future work in preparing similar visual demonstrations of resolution information.

This study was performed for the National Aeronautics and Space Administration Headquarters, Code ETS-6, Washington D.C., under Task Order 28, Contract No. NASW3358. This task was a comprehensive effort by several companies and governmental agencies. From the private sector, OAO Corporation coordinated the activities and its subcontractor, GeoSpectra Corporation, provided the original imagery for this study. From the federal sector, the National Oceanographic and Atmospheric Administration (NOAA) administered the efforts of the other federal agencies. These included the U.S. Geological Survey's EROS Data Center which reproduced the data and disseminated copies to the U.S. Department of Agriculture, U.S. Geological Survey, U.S. Army Corps of Engineers, Central Intelligence Agency, and NASA Field Centers for analyses and evaluation for information content.

This report was prepared by OAO Corporation.

SECTION 2. INTRODUCTION AND BACKGROUND

In November 1979, the President provided the framework within which a civil operational land remote sensing satellite system would be implemented. The National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce in addition to its ongoing atmospheric and oceanic responsibilities, was assigned the management responsibility for operational civil remote sensing activities.

During the interim operational phase of the program, based on the Landsat D series of satellites, NOAA will manage the systems in coordination with an interagency Assistant Secretary level Program Board. In addition, the Secretary of Commerce will establish a Land Remote Sensing Satellite Advisory Committee with representatives from state and local governments, other domestic non-Federal users, and interested domestic private sector groups. Within NOAA, a new major line component, the National Earth Satellite Service, has been proposed to have managerial responsibility for the operational civil land remote sensing satellite program.

NOAA recognizes that user requirements should determine the design of the fully operational land remote sensing satellite system. A survey of governmental and private users indicated a wide range of requirements which could justify different types of satellite systems, depending on the type of application being considered. In order to identify these requirements, it is important for the user community to have a more uniform understanding of the varying information content of data at different spatial resolutions for a variety of applications (e.g., forestry, agriculture, urban studies, geology).

The NOAA Federal User Agency Working Group in April 1980 received an unsolicited proposal from GeoSpectra Corporation to develop the necessary materials for a visual demonstration of data at various resolutions. It was the group's belief that there was merit in having general-purpose examples of products expected from future spaceborne multispectral imaging systems, if the simulated products could be developed at a reasonable cost and could be produced with the technical fidelity required to faithfully

represent the information content expected of future materials. NOAA felt the GeoSpectra proposal could meet these requirements and the materials GeoSpectra was to prepare would prove valuable to many user organizations. Therefore, this task was initiated to provide a low cost demonstration of the relative utility of multispectral data at different levels of spatial resolution. In addition, this task would assist NOAA in understanding the user community requirements necessary to develop a responsive operational system.

NASA/OSTA was made aware of the Geospectra proposal and decided to jointly sponsor this activity with NOAA. OAO Corporation was tasked to perform the technical management of the study because of its existing contract with OSTA. Geospectra was to participate in the study as a subcontractor to OAO.

SECTION 3. OBJECTIVE AND METHODOLOGY FOR PERFORMING THE TASK

This section presents the methodology employed to produce the final objective of the task: a camera-ready layout of the images and text for a resolution brochure. The objective and methodology are presented in subsection 3.1 and 3.2, with more detailed discussions of the methodology found in subsections 3.2.1 through 3.2.4.

3.1 OBJECTIVE OF THE STUDY

The final objective of this project was to provide NOAA with a full-color brochure demonstrating the effect of varying resolution on the information content in multispectral scanner data. This brochure would contain imagery of data at different resolutions for several test sites, as well as a narrative discussing the information obtainable from the various resolutions. Copies of this brochure were to be distributed by NOAA to the user community at the Spring 1981 user requirements meetings. The brochure would be an aid to the layman in understanding the relationship between resolution and information content in multispectral scanner data.

The specific objective of this task was to produce the camera ready layout of this brochure. The actual printing of the brochure was to be performed as a separate activity. Meeting the specific objective of this task required the performance of several major activities including, data acquisition and processing, image product generation and reproduction, data analysis and interpretation, and compilation of results for the brochure layout. These activities are discussed below.

3.2 METHODOLOGY-OVERALL STUDY PLAN

OAO Corporation was given the responsibility to coordinate the activities of all participants in this task. This included a subcontract to GeoSpectra Corporation to generate the original simulated data. The data would be made into imagery covering four test sites which were representative of the applications disciplines of forestry,

agriculture, urban (land use) studies, and geology. The spatial resolutions that were to be simulated for each site were 10m, 20m, 30m, 40m, and 80m.

The EROS Data Center had agreed to prepare, at no cost to the project, the necessary reproductions of the simulated resolution imagery and digital tapes which Federal User Agencies would use to perform an analysis and evaluation for information content. These agencies were the U.S. Department of Agriculture, U.S. Geological Survey, U.S. Army Corps of Engineers, Central Intelligence Agency, and NASA.

The final step in this task was for OAO to take the imagery, and the results from the analysis and evaluation, and prepare the layout of imagery and textual materials. This layout was to be in ready-for-print format, that could be used to prepare the simulated spatial resolution brochure.

3.2.1 PREPARATION OF THE SIMULATED DATA

This phase of the task was to be accomplished by a subcontract issued by OAO Corporation to GeoSpectra Corporation of Ann Arbor, Michigan. It was the responsibility of GeoSpectra to provide the basic multispectral scanner data on digital magnetic tapes (with documentation) and corresponding image products required in the production of the brochure.

GeoSpectra obtained high resolution multispectral scanner data from an aircraft mounted Daedalus DS-1260 scanner. The data had been collected previously and were supposedly available from the Daedalus Corporation and EG&G. The data were to provide an approximate coverage, for each of the four test sites, of 4.8 Km (3 miles) x 11.3 Km (7 miles). It was planned that the forestry, agricultural, and urban test sites would be prepared from scanner data collected at approximately 3000 m (10,000 feet) altitude over an area in Eastern Tennessee near noon on April 1, 1977. The geological test site was to be a semi-arid area in the Western United States which was covered by a Daedalus scanner flight flown for the Department of Energy by E.G.&G. The resolution of all of these test site data was 8.25 meters.

GeoSpectra was to create a 10 meter resolution data set for each site by re-sampling the original data. Then 20m, 30m, 40m and 80m resolution data sets were to be simulated by averaging multiples of the 10m resolution pixels. From these digital data GeoSpectra would produce three-channel, contrast-stretched color composite images of each test site area with simulated spatial resolutions of 10m, 20m, 30m, 40m, and 80m. An 8 inch x 10 inch color positive transparency was to be produced at approximately 1:76,000 scale for each of the test areas. Each positive transparency would contain 5 images (one for each spatial resolution) for each test area.

In addition to the imagery, GeoSpectra would provide a minimum of 2 copies of the magnetic tapes containing the digital data for use during the data analysis phase portion of the task. The digital tapes and support documentation would be provided for each test area, and would include the raw data, straight data in files, and contrast stretched data.

To prepare the digital data, the computer processing was to be done with GeoSpectra's software on the University of Michigan's Amdahl 470V/7 computer and the image products were to be produced on GeoSpectra's Optronics photowriter device. GeoSpectra was to document the processing steps used in the generation of both the digital and image products in a report accompanying the deliverable products (This report is included as Appendix A).

3.2.2 REPRODUCTION OF THE ORIGINAL SIMULATED DATA

The second phase of this task was to have the EROS Data Center (EDC) in Sioux Falls, South Dakota reproduce the GeoSpectra image and tape products. EDC was to utilize the color positive transparencies to prepare paper prints of the image data at the five spatial resolutions. The 8" x 10" transparencies (1:76,000 scale) were to be reproduced for each test area to provide the paper prints at scales of 1:25,000, 1:50,000, and 1:100,000. A sufficient number of copies were to be reproduced to provide a set for each of the participating user groups. The digital

tapes from GeoSpectra were also to be duplicated by EROS to provide a set for each user group.

The package of products that EDC produced for each Federal Users Agency Working Group to use in its analysis was to include the following for each test site area:

- o Two tapes containing geometrically corrected data.
- o Two tapes containing data to which have no geometric corrections have been applied.
- o Color composite positive transparencies.
- o Color composite paper prints.
- o Documentation concerning the production of these products.

The EROS Data Center also had the responsibility to make the digital and photographic data available to any requestor. EROS participation in this project was to be on a no-cost basis. Appendix B of this report provides an explanation of the digital and photographic products EROS generated.

3.2.3 USER AGENCIES ANALYSIS OF SIMULATED RESOLUTION DATA

In the third phase of the task the imagery and digital data were to be disseminated to NOAA's selected user agencies. They were to perform a detailed analysis to determine the information content which the various resolutions provided as it applies to the four scientific applications. The agencies performing these analyses were the Corps of Engineers, Department of Agriculture, Department of Interior (USGS), Central Intelligence Agency, and NASA. The agencies were not to be reimbursed for their analysis costs.

The Corps of Engineers was to perform their analysis using the digital data on tape, while the other agencies would utilize the imagery. The results of their analyses was to be the input for the textual material in the brochure. OAO working with NASA and NOAA would coordinate this effort to assure completion of these studies; however, it would be NASA and NOAA's responsibility to see that these analyses were completed on

schedule. OAO was to receive the results of the agencies work for use in preparing the layout for the brochure.

3.2.4 PREPARATION OF RESOLUTION BROCHURE

In the final phase of this task, OAO would be responsible for using the imagery provided by EDC and the evaluation reports from the user agencies to prepare the layout of the brochure. OAO was to provide the technical and graphic arts expertise to compile and lay out the final ready-for-print graphic materials for use in printing the final brochure. OAO was to turn over to NOAA the final layout work and NOAA would have the responsibility for coordinating the final printing effort.

SECTION 4. ACTUAL TASK PERFORMANCE

During the performance of this task, many departures from the original plan took place. This section documents what actually occurred in the various phases of the study. Each of these departures was not considered too serious when it occurred, however, when combined they resulted in long delays and had a significantly detrimental effect on the project. It is for this reason that these departures are worthy of examination.

4.1 PREPARATION OF THE DATA

The aircraft scanner data that GeoSpectra used for the urban, agriculture, and forestry sites were previously acquired by Daedalus Corporation with their DS1260 multispectral scanner. However, these data were flown on December 10, 1977; not the optimum season for imaging forestry or agricultural areas, and not the April 1, 1977 date that was originally proposed. Using data collected in December seriously limited the information content which was discernable in the agricultural and forestry sites.

The Daedalus scanner data that EG&G provided for the geologic site was not of the area originally proposed and did not contain sufficient geologic phenomena. Therefore, it was decided to use data from a different scanning system, the Thematic Mapping Simulator (TMS) that had been flown over a geologic site in Table Rock, Wyoming. It took additional time to receive the TMS data from the Jet Propulsion Laboratory, and resulted in a two month delay, from October until December, 1981, in GeoSpectra delivering their data products. In addition, this scanner differed from the Daedalus DS-1260 in that its data had different spectral bands, different resolutions (TMS 12.67m, Daedalus 8.25m), and was not of the same geometric fidelity.

The documentation which GeoSpectra prepared for this study is provided in Appendix A of this report. The information which describes how the simulated resolution data at 10m, 20m, 30m, 40m, and 80m resolutions

were produced does not adequately explain the techniques used. GeoSpectra claims that this information is proprietary, which prevents them from providing the further explanations or the algorithm used to generate the simulated data. This resulted in the Federal User Agencies' criticism and confusion about the data products during their attempts to analyze and evaluate the information content in it.

4.2 REPRODUCING THE DATA SETS

Upon receiving the original data from GeoSpectra, the EROS Data Center was scheduled to produce in one month the copies of the data package for the Federal User Agencies to perform their analyses and evaluations. However, budgetary constraints did not allow EROS to provide the digital and photographic data at "no cost" as originally planned. Thus, before the data could be produced, NOAA had to provide funding to cover EDC's costs. This caused further time delays and resulted in the data not being available to the user agencies until late March 1981.

It was then apparent that the original completion date of April 1981 could not be met and the publication of the brochures for distribution at NOAA's Spring meetings with the civil land remote sensing user community was not possible. NOAA thus agreed to a later date for publication of the brochures.

4.3 USER AGENCY ANALYSIS

In March 1981, the Federal User Agencies Group received copies of the data packages that had been compiled and disseminated by the EROS Data Center. The Federal Agencies that were to perform the primary analyses and evaluations, on a voluntary basis, were the Department of Agriculture, the U.S. Geological Survey, the Central Intelligence Agency, and the U.S. Army's Corps of Engineers. Copies of the package were also made available to NASA's Earth Resources Regional Centers for additional analyses of the data if time and funding permitted. Written results of a digital analysis evaluation were received from one regional center; however, it was theoretical in form and was not considered germane to this task.

The user agencies were originally scheduled to complete their analyses in about one month after receiving the data. This was an exceedingly optimistic schedule because, for variety of reasons which are explained in Section 5, it was late Fall 1981 before final results were obtained from some of the agencies. One agency was never able to complete its evaluation and did not submit a final report.

Thus in December 1981, OAO Corporation received the final inputs to begin preparing the final report to this task.

4.4 COORDINATION, MONITORING, AND PREPARATION OF BROCHURE LAYOUT

After the data preparation phase of the project, OAO Corporation interfaces were limited to NOAA and NASA only. OAO worked through the NOAA/NASA contacts to monitor the progress of the work being performed by the government agencies (EDC, USGS, USDA, CIA, COE, etc). This method limited OAO's effectiveness in coordinating the activities for this study.

By the time OAO received the individual agency reports, the scope of their phase of the task had been revised by NOAA and NASA. Because of the extensive delays throughout the task and the problems with the data, it was decided that OAO would write a final report; in addition to providing the resolution imagery in a layout format for the brochure. The final report was to document everything that had transpired during this task and provide recommendations for improvements if any future projects of this nature should be undertaken.

SECTION 5. RESULTS FROM USER AGENCY ANALYSIS

This section presents the results obtained from the Federal User Agencies' analysis and evaluation of the simulated resolution data. In addition, several limitations and problems which adversely affected the results of this analysis are discussed.

5.1 RESULTS FROM THE USER AGENCY ANALYSES OF THE DATA

The user agencies were asked to evaluate the simulated resolution data to determine such factors as 1) the retrievable information content of the digital imagery at the various resolutions; 2) the processing load, equip-ment requirements, and projected costs for digital analysis at various resolutions and, 3) the value/cost relationships attainable at various resolutions. However, due to a variety of reasons discussed in subsection 5.2, the user agencies primarily performed a visual analysis of the image products.

Presented below is a synopsis of all of the user agency visual analyses of the image products. By agreement with the user agencies, these results were not to be presented individually for each user agency. Therefore the results presented below are a synopsis of the visual interpretations of the paper print images and the examination of the digital data on a CRT screen. These results were given to OAO in written report form and by oral presentation.

5.1.1 URBAN SITE

Maryville, Tennessee, is a small city of 14,000 persons located 10 miles south of Knoxville. The entire urban test site includes a range of resi-dential densities, commercial and industrial areas and intrastructure such as roads, airports, etc. Additionally, some forest stands and agriculture are contained in the image, making land cover type comparisons a possibility without the necessity of accounting for atmospheric and temporal effects. The entire Maryville, Tennessee, test site covers an area of 4.85 km by 12 km.

Based upon the visual interpretation the 10m resolution data can delineate Level I land use categories with reasonable accuracy. Level II categories were separated and delineated with mixed degrees of success. Identification and classification of features at this level is especially difficult when no supplementary data are available to aid in the classification and in areas where the areal extent of the feature is less than an order of magnitude larger than the image pixel size.

The measurement of acreage for various land use categories, at least in the center of the print, was possible with reasonable accuracy (80-90%). It is possible to identify the major uses, such as the airport in the urban area, the various urban centers and business districts. A distinction between industrial areas and residential areas can be made. The major highways show up fairly well. At 10 meters, individual houses or structures can be seen.

There appears to be more "blockiness" in the 30 meter resolution when compared to the 20 meter resolution. The 30 meter resolution appears to be a key point, a breaking point. Drainage patterns disappear at about 30 meters and there is trouble delineating riparian vegetation at 30 meter resolution. For the urban test site the 80 meter resolution, as a print, was not useful. One can only determine broad proportions of various uses but would have difficulty in determining individual uses without extensive ground reference.

5.1.2 AGRICULTURAL SITE

The agricultural site is located in the Binfield and Blockhouse areas in Eastern Tennessee. The data for this site were collected in the December time period and thus was considered not optimum for an agricultural analysis.

At 10 meters, fields can be located, delineated, and measured. Wooded areas are easily distinguishable and the power line trace was quite observable. For the most part the conclusions for the agricultural test site would be the same as those of the urban test area with the exception of an emphasis toward crop land. It is possible to get some

idea of the terrain, that is, the wooded hills, roads, and individual structures, and bare ground or plowed ground can be determined. At 80 meters, as with the other test sites, only broad patterns are observable, and visible inspection without related ground reference materials is not possible. A comment made during the agricultural examination can summarize the observations: "Ten meters is better than 20, and 20 is not much better than 30. Beyond 30 meters, visual inspection is marginal.

5.1.3 FORESTRY SITE

The forestry site is located in the Appalachian Hills area near Maryville and Calderwood in Eastern Tennessee.

A concern was expressed that for forestry analysis the selected test period was not optimum. In fact, "the site looked more like a geology test site than a forestry site". It was noted that one could not interpret in the deep shadows which were present on the print.

The forested areas were distinguished from all other Level I categories at both 10 and 30 meters. Even small, narrow plots and individual tree rows could be delineated. In areas of dense growth, tree height crown diameter, stem diameter, species, etc., could not be determined. Since the imagery used in this analysis was acquired in December when the deciduous trees had no foliage, accurate classification and delineation of deciduous, ever-green and mixed areas was difficult. If 10 meter resolution multitemporal imagery (leaves on and leaves off) were available this distinction could probably be made even visually without too much difficulty.

At 10 meters it is possible generally to delineate forest versus non-forest and identify and delineate drainage patterns. The major roads and some secondary roads can be traced. Finally, forest density can be categorized into several classes, e.g., closed canopy vs. open canopy, etc.

General Observations

It was the judgment of the User Agencies that the analysis would have to be labeled inconclusive for agriculture and forestry due to the seasonal nature of the imagery. The crop areas did not show the presence of the growing crops. Further, it was the opinion of the group that the agricultural test site was inadequate because field sizes were too small.

5.1.4 GEOLOGY SITE

The geology site is located near Table Rock, Wyoming. The Table Rock oil and gas field is in the lower central part of the test site, just left of the railroad tracks. At 10 meter resolution, there was a good delineation of the type of surface material. The detection of individual trees or clusters of vegetation and vegetation patterns can be made. Also observable on the 10 meter simulated imagery generated by Thematic Mapper Simulator were powerline traces, secondary roads, and possibly, irrigated areas. On the geology site imagery, one can see major drainage patterns and determine broad land forms and can appraise topography.

As with the urban test site, 30 meter resolution appears to be a break for visual inspection of prints. Some indication of land form is still present; however, at resolutions of 30 meters and coarser, this appears to be marginal. For the geological test site, only broad patterns appear in the 80 meter data, and it is not possible to determine content without supporting ground information.

5.2 LIMITATIONS TO THE USER AGENCY ANALYSES

Presented in this subsection are some of the problems and limitations which were encountered during the user agency analysis phase of this project. In some cases these limitations were identified by the user agencies while others were observed by OAO during the course of the project. It is the opinion of OAO that the combination of these problems resulted in a significant reduction in the quality of the analysis results. The analyses were not as thorough or quantitative as

originally envisioned or conducted within the schedule of the project due to the problems discussed below.

5.2.1 LACK OF GROUND TRUTH

The most significant problem that limited the analysis of the resolution data was the lack of ground truth. It was stated by a user agency:

"Visual analysis of the spatial information content of the imagery without prodigious amounts of supplementary information proved to be of limited usefulness. Even though features were visually distinguishable, their functional utility could not always be determined and the accuracy of their classification could not be verified. It is expected that digital analysis of the imagery, supported with limited ground truth data, would provide an enhanced interpretation and classification capability and would produce significantly improved overall results."

The lack of ground truth information on the four test sites was a serious oversight in the original planning for this task. It should have been a mandatory requirement that some ground truth information accompany the data (imagery) so comprehensive analysis and evaluation could be performed with greater accuracy. Because there was no ground truth, the user agencies felt very constrained in performing the analysis work, and only very limited digital analysis was performed on the data.

Efforts were initiated by the agencies to acquire supplementary data from other sources to support their planned evaluation. However, the only supplementary data sources that were located were USGS quad sheets for each test site and low altitude color infrared photography of the urban test site. These data sources were only partially useful in performing the evaluations.

The user agencies, without adequate supporting data, decided to perform primarily a visual evaluation to determine the information content for the various resolutions for each of the test sites.

5.2.2 PROBLEMS WITH THE ORIGINAL DATA

There were several problems with the original simulated data produced by GeoSpectra Corporation. First, the fact that two different multispectral scanners were used resulted in the geology test area data being of a lower quality than the data created from the DS-1260 scanner. The Thematic Mapper Simulator scanner had an inconsistent mirror velocity and was flown at a different altitude which caused the "geometric fidelity" of the geology test site imagery to be inferior to that of the other three sites. These inconsistencies were not considered a critical problem, however, they created another unknown variable in an already complex and confusing situation.

In addition, the time of year at which the data were collected severely limited the analysis that could be performed on two test sites. The agriculture and forestry sites were flown in December which is less than optimum for delineating vegetative patterns. This factor caused further criticism of the data by the user agencies and limited the analysis for information content.

GeoSpectra added further confusion and speculation about how the imagery was prepared by not providing detailed explanations on the algorithms and techniques used. GeoSpectra regarded this as proprietary information, but because the information was not provided to the users, there was speculation about the techniques used in preparing the data. The user agencies questioned whether or not these images adequately displayed the information content attainable from data at these resolutions. In fact, one user agency spent a great deal of their analysis trying to determine how GeoSpectra had prepared the data. This was not what was intended for the user agency to do, and a more useful analysis could have been performed if GeoSpectra had provided complete and detailed documentation about the preparation of the resolution data.

5.2.3 IMAGE DISPLAY PROBLEMS

The user agencies expressed concern about the visual rendition of the 80m resolution data when displayed at the three selected scales of

1:100,000, 1:50,000, and 1:25,000 images. At these relatively large scales (which are at least 10 to 40 times greater than conventional Landsat imagery) the large pixel size and the resulting "blocky" images created a negative bias against the 80 meter resolution data. This is a critical problem with no apparent solution, because when performing a visual interpretation the larger scales are required but at these scales the large pixel size is visually displeasing. However, this is not as critical when analysis of digital data is performed using computer techniques. This one aspect of GeoSpectra's presentation of the imagery was criticized by all the user agencies who felt... "the 80m data, as presented, did not give a fair rendition of the information contained within the imagery." However, if the imagery was prepared at a smaller scale that would be "visually pleasing", then the information content could not be discerned visually for the high resolution data because the small scale would make all resolutions appear very much the same to the naked eye.

Scale will always be a factor when attempting to visually display the differences between 10m, 20m, 30m, 40m and 80m imagery. Image scale affects any visual interpretation of images for information content.

5.2.4 BUDGETARY AND MANPOWER PROBLEMS

Another factor which affected the evaluation and analysis of the simulated resolution data was budgetary problems within the government agencies. The user agencies had agreed to perform their work on a volunteer basis, and at no cost to the task. However, the budgetary constraints of 1981 limited the level of effort that each agency could assign to performing the analysis. This resulted in delays in receiving the results from the user agencies, and caused one agency not to submit any results.

5.2.5 LACK OF COMMITMENT AND ANALYSES GUIDELINES

The numerous time delays encountered in all phases of this task, which prevented the resolution brochure from being completed on schedule, can be attributed in part to a lack of firm commitment by the agencies

involved in this study. These delays were undoubtedly compounded because the agencies had originally volunteered to participate in the project. When budgetary constraints arose, the agencies were unable to contribute the manpower and resources as planned.

The dual leadership by NASA and NOAA was a detrimental factor in the management of the project. In addition, NASA and NOAA purposely provided very limited guidelines to the user agencies as to what was expected in accomplishing their analyses and evaluations of the data. In retrospect, this was too loose a framework which resulted in confusion and lack of clear cut areas of responsibilities. The results of the user agency analyses reflect this lack of direction:

- o None of the user agencies attempted to perform a digital analysis of the data due primarily to lack of ground truth. Digital analysis was considered an integral part of the evaluation process at the outset of the project. It would have been beneficial to this task to have at least one agency perform a simplified Level I digital classification to obtain some quantitative results about the informational content between the various resolution images.
- o One agency apparently utilized a major portion of its analysis effort attempting to identify how Geospectra created the original resolution data.
- o The final reports from the user agencies were brief and only summarized visual interpretations performed on the paper print images. Also, one agency did not submit any report on its evaluation.

SECTION 6. CONCLUSIONS AND RECOMMENDATIONS

This section presents the general conclusions which can be drawn from the results of this study. Included are some observations about the methodology employed in the study as well as comments on major deviations from the study plan throughout the task. Also, some of the technical aspects of the study are critically examined. From these conclusions, several recommendations have been formulated as guidelines for future activities of this kind. These recommendations are presented in subsection 6.2.

6.1 CONCLUSIONS

The most significant conclusion which must be reached is that this project was not successful in terms of its overall objective. Technically, the layout for a resolution brochure has been produced but it is apparent that the brochure will not be printed. This is primarily because of the schedule slippages which occurred during the project and serious reservations about the quality of the resolution data products and the user evaluations of those products. Although the specific use for this brochure (the Spring 1981 NOAA Users Meetings) has passed, the concept of such a "resolution brochure" demonstrating information content for various data resolutions is still valid. It appears the user community would still benefit from such a tool, particularly in the process of establishing user requirements for remotely sensed data. From that standpoint it is likely that the most valuable results of this project are the "lessons" learned in conducting it. These lessons can make a significant contribution to the successful completion of a project of this kind in the future.

Another important observation which must be made about this project is the number of deviations from the original study plan which occurred through-out the study. These deviations, such as schedule slippages, changes in the data sets, and loss of user agency support were detrimental to the study. However, what may be equally significant is that the design and organization of this study permitted these

deviations to occur. Some of the negative aspects of the study design as well as other specific conclusions about the project are presented below:

- o There was a large number of agencies or groups participating in this project. Since most of them were participating on a voluntary basis, their commitment to the project was not strong enough. OAO lacked the authority to enforce schedules or require performance by the participants, since they were for the most part government agencies volunteering to contribute. In addition, the dual leadership of NASA (funding) and NOAA (requiring the results) led to confusion about areas of responsibility. The overall framework of the project was too loose and success of the project depended upon too many interactions and factors beyond the control of the individual participants.
- o Federal budgetary constraints severely impacted this project. Because the agencies were volunteering to participate, they were often unable to devote the manpower or resources to the project at the levels they originally offered. This caused significant delays throughout the project and lowered the quality and extent of the user evaluations.
- o The lack of ground truth for the study sites hampered the user agency analysis of the data products. All of the user agencies mentioned this limitation. There was no specific requirement for ground truth specified in the original study plan.
- o Several problems were identified with data used for the study. Data from the time of year originally specified (April) were not available, and data from December were substituted. This severely compromised the validity of the analyses for information content in data from the agricultural and forestry sites, since vegetative patterns are much less evident at that time of the year. The geology test site data originally identified were not satisfactory and data from another scanner were

substituted. These substitute data were of lower geometric fidelity than the other data sets. Finally, the documentation on the processing techniques used to prepare the data was not specific enough. Since the user agencies had questions about how the data were produced, more complete information would have been useful in their analyses.

- o This project demonstrated that scale plays a significant role when evaluating image products which depict data at different resolutions. The user agencies stated that the lower resolution data appeared too "blocky" at the relatively large scales of the image products. They claimed this blockiness made it difficult to evaluate the information content of these data. On the other hand, these large scales were required to adequately show the information content in the higher resolution data. Scale will always affect information content of images so it may be of limited utility to use image products to try to compare information in different resolution data.
- o The lack of specific guidelines limited the quality and utility of the user agency analyses. NASA and NOAA purposely limited their guidelines, not wanting to constrain the user agencies. The result was analyses which varied widely in their approaches and generally were much lower levels of effort than expected.
- o The overall quality of the resolution data and the image products was very satisfactory. Although the user agencies and NASA criticized the data and the image products because of uncertainty about the processing techniques and the "blockiness" issue, it is the opinion of OAO that the products represent a reasonable attempt to simulate actual data of the resolutions studied. This is particularly true for the amount of money invested in acquiring the data.

6.2 RECOMMENDATIONS FOR FUTURE SIMULATED RESOLUTION IMAGERY

This task was a relatively inexpensive attempt to prepare a brochure which would visually illustrate to the user community the information content in images of various resolutions. Unfortunately, the success of the project was limited. However, a great deal has been learned about producing such a resolution brochure useful to NOAA and NASA in understanding the needs of the user community. If future attempts are made to produce a brochure, the mistakes made and problems encountered in this task should not be duplicated. Thus, the following recommendations are made for future efforts:

- o The agency(s) in charge of preparing simulated resolution data and imagery must have a uniform plan with firm guidelines of what is to be accomplished. It is important that the groups performing the evaluations know what is expected and when it needs to be completed. In addition, the number of participants involved needs to be strictly limited so the project can be properly controlled.
- o The federal agencies involved in processing and analyzing the data must be firmly committed and held to strict time lines. This may require that the sponsoring agency(s) contract for the services required rather than relying on volunteer time and manpower; especially during difficult budgetary time.
- o Adequate ground truth must be provided for all test sites, preferably obtained at the time of data collection. At a minimum, the study sites should have been studied previously for the specific applications and the necessary documentation made available (maps, reports, imagery), to the groups performing the analyses.
- o The same scanner system should be used to collect the data for all test sites to insure consistent fidelity and resolution. The data should be collected at optimum times of the year for the applications being studied; e.g., during the growing season for forestry and agriculture sites. Study sites must be

selected which adequately represent the applications of interest. For example, the urban site should be one covering a large metropolitan area with diversity and complexity - preferably a city with over 100,000 population. The agricultural site must be in an area where field size is relatively large and a diversity of crops are grown.

- o Thorough documentation on the data preparation and processing techniques must be provided to the agencies performing the data analyses. This information is valuable for understanding the visual characteristics of the data products.
 - o The data analysis should be structured and as quantitative as possible. Major emphasis should be placed on analysis of the digital data, rather than the image products. This would reduce the bias introduced by scale when evaluating the image products. Analysis of the digital data would provide more definitive results on the informational content that each resolution can provide.
-
- o Further study should be undertaken to determine the optimum scale at which the images should be produced in a resolution brochure.

Appendix A

Report on Simulation of Multispectral Scanner Data
GeoSpectra Corporation

Simulating the Effect of Spatial Resolution
on Satellite Imagery Using Aircraft
Multispectral Scanner Data

David Coupland
Geomathematician

January 19, 1981



GeoSpectra
CORPORATION

320 NORTH MAIN, SUITE 301

ANN ARBOR, MICHIGAN 48104 U.S.A.

Simulating the Effect of Spatial Resolution
on Satellite Imagery Using Aircraft
Multispectral Scanner Data

An orbiting multispectral scanner system such as LANDSAT produces a digital image of the Earth beneath composed of an array of discrete picture elements or "pixels". The spatial resolution of such a digital image is related to the size on the ground of a single pixel, which depends on the optical characteristics of the multispectral scanner and the altitude of the satellite. A higher spatial resolution image (smaller pixel size) allows the identification of smaller ground features, but also generally covers a smaller total area. A lower resolution image will only show large ground features but provides the convenient synoptic view of a large area which has made Earth resource imagery so useful. For the design of future satellite systems it will be necessary to select a pixel size which produces the best balance between the opposing needs of good spatial resolution and synoptic view.

In this study we illustrate the effects of varying pixel size on image usefulness by specially processing aircraft multispectral scanner data. Spatial resolutions of 10 meters, 20m, 30m, 40m, and 80m have been simulated for each of four test areas. The test areas provide examples of four land use categories of interest to remote sensing users: urban, agriculture, forest, and geology. The place and time of collection of the aircraft data sets is given in Table 1.

Table 1. Information on Original Aircraft Multispectral Scanner Data

<u>Land Use Category</u>	<u>Source of Data</u>	<u>Multispectral Scanner</u>	<u>Date of Collection</u>	<u>U.S.G.S. Quadrangles</u>	<u>Aircraft Altitude Above Ground</u>
Urban	Daedalus Enterprises	Daedalus DS-1260	12/10/77	Maryville, Tenn.	3048m
Agriculture	Daedalus Enterprises	Daedalus DS-1260	12/10/77	Binfield, Tenn. Blockhouse, Tenn.	2970m
Forest	Daedalus Enterprises	Daedalus DS-1260	12/10/77	Maryville, Tenn. Calderwood, Tenn.	2983m
Geology	Jet Propulsion Laboratory	Thematic Mapper Simulator		Table Rock, Wyoming	4800m

Digital Image Processing

The aircraft data was received in partially processed form: formatted for computer processing but without geometric or radiometric corrections. The first processing step was to combine the aircraft multispectral channels as necessary to simulate LANDSAT spectral channels 4, 5, and 7 (those normally used to produce three color imagery). As indicated in Table 1, the urban, agriculture, and forest test areas were imaged with a Daedalus DS-1260 multispectral scanner, while the geology test area was imaged with the Thematic Mapper Simulator. Table 2 lists the wavelength bands for the spectral channels on the two aircraft multispectral scanners and LANDSAT.

LANDSAT channels were simulated as either a single aircraft channel with approximately the same wavelength band, or as the average of two adjacent channels which together cover the required spectral region. Averaging two channels is equivalent to adding their values then halving the gain - close to the physical situation of a single spectral filter. The aircraft channels used to simulate LANDSAT are also shown in Table 2. Ideally Daedalus DS-1260 channels 4 and 5 would have been averaged to simulate LANDSAT channel 4, but in the particular data available channel 4 was very noisy and could not be used. Hence DS-1260 channel 5 was used alone to simulate LANDSAT channel 4.

Table 2. Characteristics of Multispectral Scanners

	Channel Number	Wavelength Band (μm)	Used to Simulate LANDSAT Channel
Daedalus DS-1260	1	.38 - .42	
	2	.42 - .45	
	3	.45 - .50	
	4	.50 - .55	
	5	.55 - .60	4
	6	.60 - .65	5
	7	.65 - .69	
	8	.70 - .79	
	9	.80 - .89	7
	10	.92 - 1.10	
	11	8 - 14	
Thematic Mapper Simulator	1	.45 - .52	
	2	.52 - .60	4
	3	.63 - .69	5
	4	.76 - .90	7
	5	1.00 - 1.30	
	6	1.55 - 1.75	
	7	2.08 - 2.35	
LANDSAT	4	.50 - .60	
	5	.60 - .69	
	6	.70 - .79	
	7	.80 - 1.10	

Geometric corrections were performed in two stages. In the first stage, the altitude of the aircraft above ground was determined by locating two ground control points which lay in the same scan line of image data. Comparison of their ground distance with their separation in the image yielded the altitude. Usually this was done several times for each scene. The assumption employed was that the angular separation between adjacent pixels was constant, i.e., the rotating mirror which scanned the Earth by directing the light to the sensing elements moved with constant velocity. See Figure 1. This assumption produced very consistent results for the Daedalus DS-1260 data, yielding well constrained altitudes. However we were unable to obtain consistent results with the Thematic Mapper Simulator data. The computed altitude depended on the location in the scan line of the ground control points used, indicating that mirror velocity was not constant. Consequently the geometric fidelity of the geology test image is not as good/as that of the other three.

Another key parameter measured at this stage was the width of the scan lines on the ground, or the meters of flight path per scan line. This is the velocity of the aircraft in meters per second divided by the number of mirror scans per second (100 mirror scans/second for the DS-1260 data). Meters per scan line was measured by locating two ground control points along the flight path and comparing their image separation with their map separation.

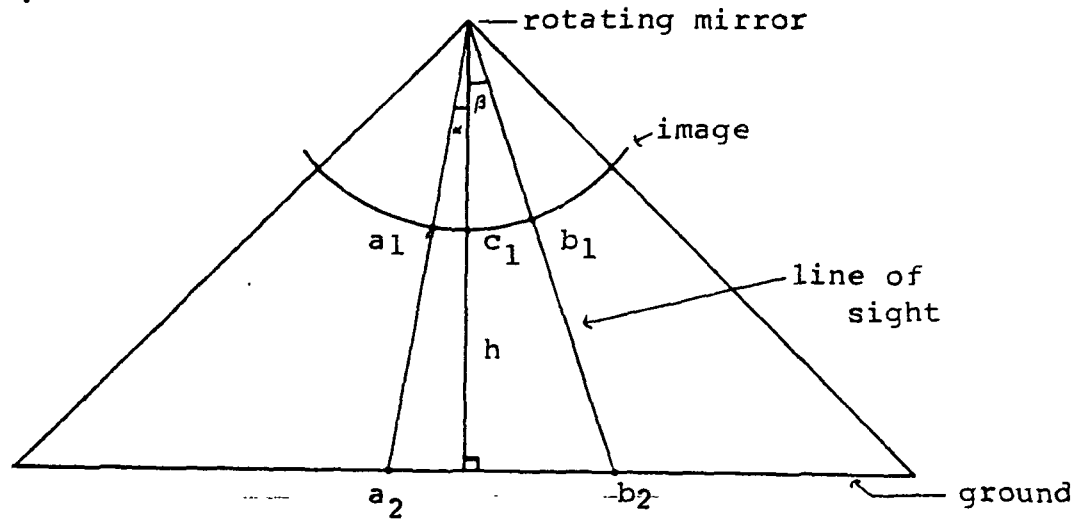


Figure 1. Determination of aircraft altitude.

Two ground control points a and b along a single scan line are located in the image (a_1, b_1) and on a map (a_2, b_2). The distances in pixels from the center of the image $d(a_1, c_1)$ and $d(b_1, c_1)$ multiplied by the angular sampling interval are the angular positions α and β . With these angles and the map distance $d(a_2, b_2)$ the altitude h may be computed.

With the altitude and meters per scan line parameters, the original data was systematically corrected to remove two types of distortion. Rather than a constant angular separation between adjacent pixels in a scan line as in the original data, we require a constant ground distance between pixels, which is the pixel size (scan angle effect). Also, we require that the width of the image lines equal the width of the pixels within each line, i.e., the pixels should be square (overscanning effect). Both distortions were removed via along scan line nearest neighbor resampling.

The second stage of geometric corrections consisted of resampling the images to a particular map projection. The Universal Transverse Mercator projection was used since this is the standard for LANDSAT imagery. Seven to ten ground control points were located in each image. A least squares linear or bilinear polynomial was computed for each image that related the image coordinates (line and pixel) to the UTM coordinates. The image was then nearest neighbor resampled according to this polynomial. During resampling all images were reduced to a width of 4800m (about 3 miles).

The primary distortion removed by this process was due to "crabbing" of the aircraft, meaning that the aircraft was not pointed exactly in the direction of motion. This caused the scan lines to be other than perpendicular to the flight direction, and the outline of the image on the ground formed a parallelogram

rather than a rectangle. Over such a small area UTM is essentially a flat earth rectangular projection.

Image Quality

Since a low order polynomial was used for the resampling, the ground control points were not matched exactly to their UTM counterparts. The residual errors between these ground control points provide a measure of the accuracy of the resampling. Table 3 lists typical and maximum residual errors between the ground control points for all four images, along with other geometric information. The DS-1260 images show internal errors of 20 to 40m except where significant elevation differences are involved. Unlike LANDSAT, which has a fairly narrow scan angle, aircraft images look to the side 45° or more. At 45° , a 100m ridge will appear 100m closer than it actually is. The maximum scan angle is about 39° for the final DS-1260 images (urban, agriculture, forest) and about 27° for the Thematic Mapper Simulator (geology). Hence topographic effects can introduce major deviations from map fidelity.

Table 3 also lists the UTM limits of each of the DS-1260 images. North is toward the top of the image for the agriculture test area, and toward the bottom of the images for the urban and forest test area (original flight directions). The flight direction for the geology test area was about $S20^{\circ}W$ (so the top of the image is toward $N20^{\circ}E$). Since the edges of this image do not run north-south UTM limits are not given in Table 3.

Table 3. Geometric Information for Imagery

Test area	Aircraft altitude ¹	Meters/scan line ²	UTM Boundaries - Final Image				Errors between ground control points	
			x-min	x-max	y-min	y-max	typical	maximum
urban	3048m	4.02	229,800	234,600	3,956,700	3,968,190 (17)	20m	30m
agriculture	2970m	4.00	767,900	772,700	3,936,000	3,946,400 (16)	30m	56m
forest	2983m	4.17	229,400	234,200	3,941,900	3,953,800 (17)	30m	39m ³
geology	44800m	12.67	see text				100m	163m

1 - above ground

2 - original data

3 - neglecting points of greatly differing elevation

(16) UTM zone 16

(17) UTM zone 17

As discussed previously the geometric quality of the Thematic Mapper Simulator data is not as good as the DS-1260 data due to the varying mirror velocity. If the exact functional form of the mirror velocity was known this data could be precision rectified as is done with LANDSAT, which also has a mirror scan velocity irregularity. For these images large errors are likely, as indicated in Table 3.

Although the geometric correction procedure involves resampling twice, once along the scan lines and once across scan lines, image degradation is not serious in the 10m resolution frames since the nearest neighbor technique was used both times. Degradation due to resampling is negligible with the lower resolution frames. If required for future applications, a specialized algorithm can be developed to limit the resampling to a single step and employ more sophisticated resampling strategies.

A Demonstration of the Effect of Varying Spatial Resolution
on Geological, Agricultural, Forestry, and Urban Test Sites

Dr. Robert K. Vincent, President

March 10, 1981



GeoSpectra
CORPORATION

220 NORTH MAIN, SUITE 201 SAN ANGELO, TEXAS 76904-1134

1. Demonstration of the Effect of Varying Spatial Resolution on Geological, Agricultural, Forestry, and Urban Test Sites

Three test sites were overflown by an aircraft containing a Daedalus DS-1200 multispectral scanner and one, the geological test site, was overflown by an aircraft carrying a Thematic Mapper Simulator. Table 1 gives the flight information. These aircraft data were computer processed by Geospectra Corporation and imaged to simulate varying spatial resolutions. Below are summaries of what Geospectra president, Dr. Robert K. Vincent, has concluded from these images. The word "pixel" on the images stands for "picture element" and refers to the smallest-sized object likely to be identifiable at that spatial resolution.

Geological Test Site, Table Rock Wyoming. Table Rock Oil and Gas field is in the lower central part of the test site just left of the parallel, black railroad tracks. Drainage patterns and fractures in the Earth's crust offer important clues concerning the favorability of subsurface structure for hydrocarbon accumulations or mineral deposits. In the 80m resolution image most drainage features easily visible in the 30m image are obscured and narrow secondary roads, such as the slanting road from top to bottom of the test site that can be seen just left of the railroad tracks in the 10m-40m images, can be mistaken for subtle fractures. Soil color, even in wavelength regions beyond the spectrum of visible light, is especially important for mineral exploration (particularly uranium, iron, nickel, copper, molybdenum, gold, silver, diamonds, tungsten, and chromium) and somewhat important for hydrocarbon exploration; hence, more channels of greater spectral range are needed. Synoptic view (a large area covered by each image) is of great importance for the mapping of fractures. Both synoptic view and greater numbers of channels become increasingly more difficult to achieve as spatial resolution is improved. Everything considered, a satellite with 30m spatial resolution and up to 15 spectral channels would be a good compromise for geological remote sensing, which is more multispectral in nature than any other Earth resources discipline.

Table 1. Information on Original Aircraft Multispectral Scanner Data

Land Use Category	Source of Data	Multispectral Scanner	Date of Collection	U.S.G.S. Quadrangles	Aircraft Altitude Above Ground
Urban	Daedalus Enterprises	Daedalus DS-1260	12/10/77	Maryville, Tenn.	3048m
Agriculture	Daedalus Enterprises	Daedalus DS-1260	12/10/77	Binfield, Tenn. Blockhouse, Tenn.	2970m
Forest	Daedalus Enterprises	Daedalus DS-1260	12/10/77	Maryville, Tenn. Calderwood, Tenn.	2983m
Geology	Jet Propulsion Laboratory	Thematic Mapper Simulator		Table Rock, Wyoming	4800m

Agriculture Test Site, Fairview, Tennessee. An electrical power line cut (a corridor of cleared land) extends from left to right across the agricultural test site. For agricultural remote sensing it is important that the area of fields under cultivation be accurately measured. Although practically all of the heavily vegetated areas (red in the image) are still observable in the 80m image, it is clear that an estimate of field size would be much more inaccurate at 80m than at 30m spatial resolution, because of the blocky appearance of the former image. A synoptic view is important for agricultural remote sensing because spectral "signatures" of different crops will likely be more uniform across a single image than between images collected at different times. A recent Scientific American article stated that half the world's agricultural fields can be resolved by an 80m resolution satellite (such as LANDSAT I, II, and III), whereas 85% could be resolved by a 30m resolution satellite. Discrimination of crops from one another, plus the separation of light-colored grains (such as wheat) from brown grass require approximately 7 spectral channels. Therefore, the 30m spatial resolution and 7 spectral channels of the LANDSAT D Thematic Mapper appear to be well suited for agricultural remote sensing.

Forestry Test Site, Six Mile, Tennessee. Appalachian hills in Eastern Tennessee cover most of the forestry test site. Inspection of the right edge of the site under a magnifying glass shows that some individual tree crowns can be identified in the 10m image, but cannot be seen in the images of worse spatial resolution. Whereas the most prominent road in the test site can still be perceived even in the 80m image, a short secondary road just left of the prominent road in the upper central portion of the test site becomes practically unobservable in the 40m image and is completely invisible at 80m resolution. The identification of individual tree crowns is important to forestry, especially in multiple canopy forests, where shorter trees and bushes grow under and between taller trees. Location of forest roads in the imagery is also important because they are the most easily

locatable landmarks on the ground for inspection teams and lumber crews. An estimation of number of board feet of timber, segregated according to deciduous (leafy) and coniferous (needle-bearing evergreens) trees, would be facilitated by increasing the number of channels from 4 to 7 and improving the spatial resolution to 30m or better. Although the LANDSAT D Thematic Mapper will greatly improve forestry remote sensing, a 10m resolution satellite would continue to improve it more than the trade-off disadvantages of a smaller area of coverage per image.

Urban Test Site, Maryville, Tennessee. The center of the urban test site is Maryville, a city with a population of approximately 14,000, located about 10 miles South of Knoxville. An airport in the extreme lower left corner of the test site can be seen at all spatial resolutions. A magnifying glass shows that half of the individual buildings that can be seen in the 10m image cannot be seen in the 20m image, and less than a quarter can be seen in the 30m image. Most roads are lost at the 80m resolution. Whereas urban remote sensing does not require as many spectral channels as the other three disciplines discussed above, it has the highest spatial resolution requirements. It is clear from these images that urban remote sensing would clearly gain from a 10m resolution satellite, even if it had only three spectral channels. Synoptic view is not greatly important for this discipline.

The final conclusions are that the LANDSAT D Thematic Mapper (30m resolution and 7 spectral channels) will greatly improve geological, agricultural, forestry, and urban remote sensing, as compared with LANDSATs I, II, and III (80m resolution and 4 spectral channels). For agriculture, the Thematic Mapper spatial resolutions and spectral channels are nearly ideal. For geology, future satellites with up to 15 spectral channels, yet with the same spatial resolution as the Thematic Mapper, are most important. Forestry eventually will require a 10m resolution

satellite with approximately the same number of channels as the Thematic Mapper. Urban remote sensing will eventually require 10m resolution, though only three channels may be necessary.

There are two types of future satellites that, as follow-ons to the LANDSAT D Thematic Mapper, could provide most of the needs of remote sensing for all four of the above disciplines. A 30m, 12 to 15-channel satellite would satisfy most of the geological remote sensing needs, while continuing the support of the other disciplines as a LANDSAT D follow-on and providing multispectral improvements in them that have not yet been well researched. A 10m, 3-channel, stereo mapping satellite would greatly aid urban and forestry remote sensing, while providing yet more improvements for geology, due mostly to the 3-dimensional viewing that stereo coverage would provide. Stereo coverage would also provide substantial aid to forestry. Therefore, a satellite with moderate spatial resolution and many spectral channels and a satellite with high spatial resolution, stereo coverage, and only a few spectral channels are recommended as LANDSAT D Thematic Mapper successors, preferably in simultaneous operation. As the test site images show, however, there is such a great improvement between current LANDSAT resolution (80m) and Thematic Mapper resolution (30m) for all disciplines that the LANDSAT Thematic Mapper should be launched as soon as possible.

Appendix B

Distribution Report Accompanying Data Package
EROS Data Center



United States Department of the Interior

GEOLOGICAL SURVEY
EROS Data Center
Sioux Falls, South Dakota 57198

IN REPLY REFER TO:

The Geospectra Corporation has been working under contract from the Department of Commerce (NOAA), on a project called "Spatial Resolution Simulation for Multispectral Sensor Images". This project has been requested by the Federal Users Agency Working Group. The EROS Data Center has the responsibility of disseminating this package to the Group. The package contains:

- A. Two tapes containing geometrically corrected images.
- B. Two tapes containing images which have no geometric corrections applied.
- C. Color composite positive transparencies.
- D. Color composite paper prints.
- E. Documentation concerning the test sets.

The EROS Data Center also has the responsibility to make the digital and photographic data available to any requesters.

The following paragraphs describe in further detail each of the items discussed above.

- A. Tapes containing geometrically corrected images.

TAPE1 titled "Resampled Aircraft Images and Geology Image Files"

- 1600 BPI, 9 track, unlabeled
- Contains seven files
 1. Urban test site (Maryville, Tenn.): resampled.
 2. Agriculture test site (Binfield, Blockhouse, Tenn.): resampled.
 3. Forest test site (Maryville, Calderwood, Tenn.): resampled.
 4. Geology test site (Table Rock, Wyoming): resampled.
 5. Geology test site: channel 4 image file.
 6. Geology test site: channel 5 image file.
 7. Geology test site: channel 7 image file.

Files 1-4 are the geometrically corrected 10m resolution images which have been resampled to a UTM map projection. The data is in Geospectra's standard format (channel interleaved - all 3 channels in one file, simulating LANDSAT 4, 5, and 7 in that order).

Files 5-7 are the image files which are imaged on an Optronics Colorwrite System to produce the transparency showing the geology test site at resolutions for the aircraft channel simulating LANDSAT channel 4. The data has already been contrast stretched over a 0-255 range.

TAPE2 titled "Urban, Agriculture, and Forest Image Files"

- 1600 BPI, 9 track, unlabeled
- Contains nine files
 1. Urban test site - channel 4 image file.
 2. Urban test site - channel 5 image file.
 3. Urban test site - channel 7 image file.
 4. Agriculture test site - channel 4 image file.
 5. Agriculture test site - channel 5 image file.
 6. Agriculture test site - channel 7 image file.
 7. Forest test site - channel 4 image file.
 8. Forest test site - channel 5 image file.
 9. Forest test site - channel 7 image file.

These files correspond to files 5-7 on tape 1 for the other test sites.

B. Tapes containing images which have no geometric corrections applied.

TAPE3 titled "Uncorrected Urban and Agriculture Image Files"

- 1600 BPI, 9 track, unlabeled
- Contains two files
 1. Urban test site (Maryville, Tenn.) [6 channels]
 2. Agriculture test site (Binfield, Blockhouse, Tenn.) [6 channels]

TAPE4 titled "Uncorrected Forest and Geology Image Files"

- 1600 BPI, 9 track, unlabeled
- Contains two files
 1. Forest test site (Blockhouse, Tenn.) [6 channels]
 2. Geology test site (Table Rock, Wyoming) [7 channels]

The areas in Tennessee and Wyoming correspond to 7½ minute quadrangle locations. The format of the four above tapes is described later in the documentation. Appendix C explains the tapes' contents as far as number of files, size of records, etc.

C. Color composite positive transparencies.

- Scale of 1:100,000
 - For all test sites
 - For all resolutions
- For a total of 4 transparencies.

- D. Color composite paper prints.
- Scales of 1:100,000, 1:50,000, and 1:25,000
 - For all test sites
 - For all resolutions
- For a total of 12 paper prints.

There are NO photographic products which accompany the raw tapes as items C and D above which are products from the geometrically corrected tapes.

- E. Documentation concerning the test sites.

The documentation that follows has been supplied to EROS Data Center by Geospectra Corporation.

The first section, Appendix A titled "Simulating the Effect of Spatial Resolution on Satellite Imagery using Aircraft Multispectral Scanner Data", is a brief description of the processing performed on the four test sites.

The second section, Appendix B, is the documentation which describes the format of the tapes. There are two header records at the beginning of each file. The first header is the standard Geospectra header described on page B1. The second header is the original Daedalus header, which is described in the document starting on page B2.

If there are any further questions, please contact Mr. Ron Risty, User Services Section, EROS Data Center. Tel. (605) 594-6151.